New Type of DPP Source for EUVL Based on Liquid Tin Jet Electrodes (P19)

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«RnD-ISAN»

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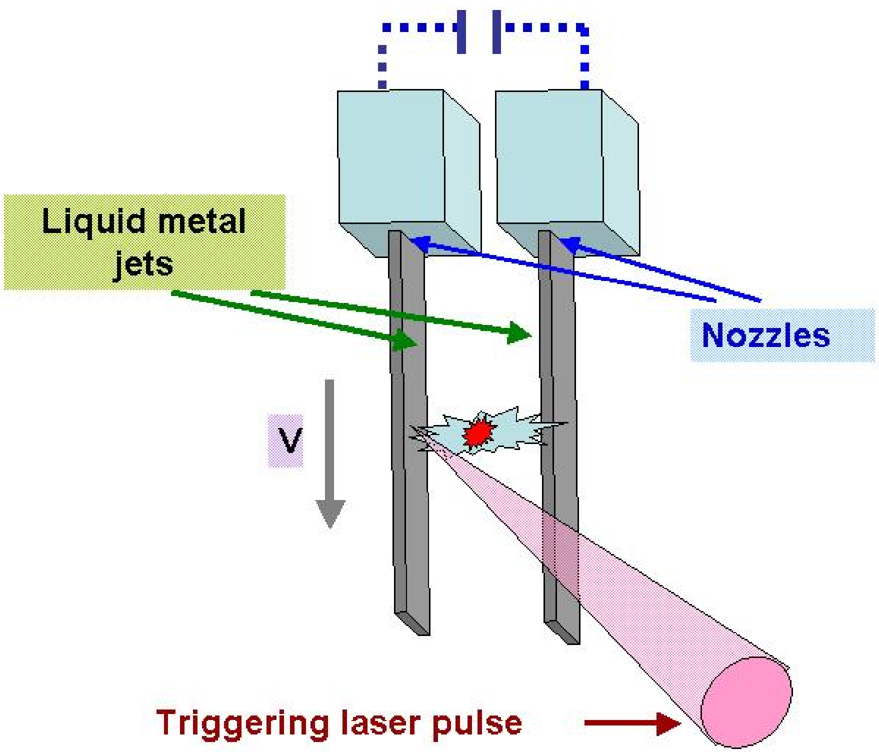
New approach source based on liquid metal jets electrodes with in-built mechanisms of:

- **Debris mitigation features**
- **High heat power dissipation**
- **Continuous source multiplication**
- **Circulation and rectification of working material**

Solution:

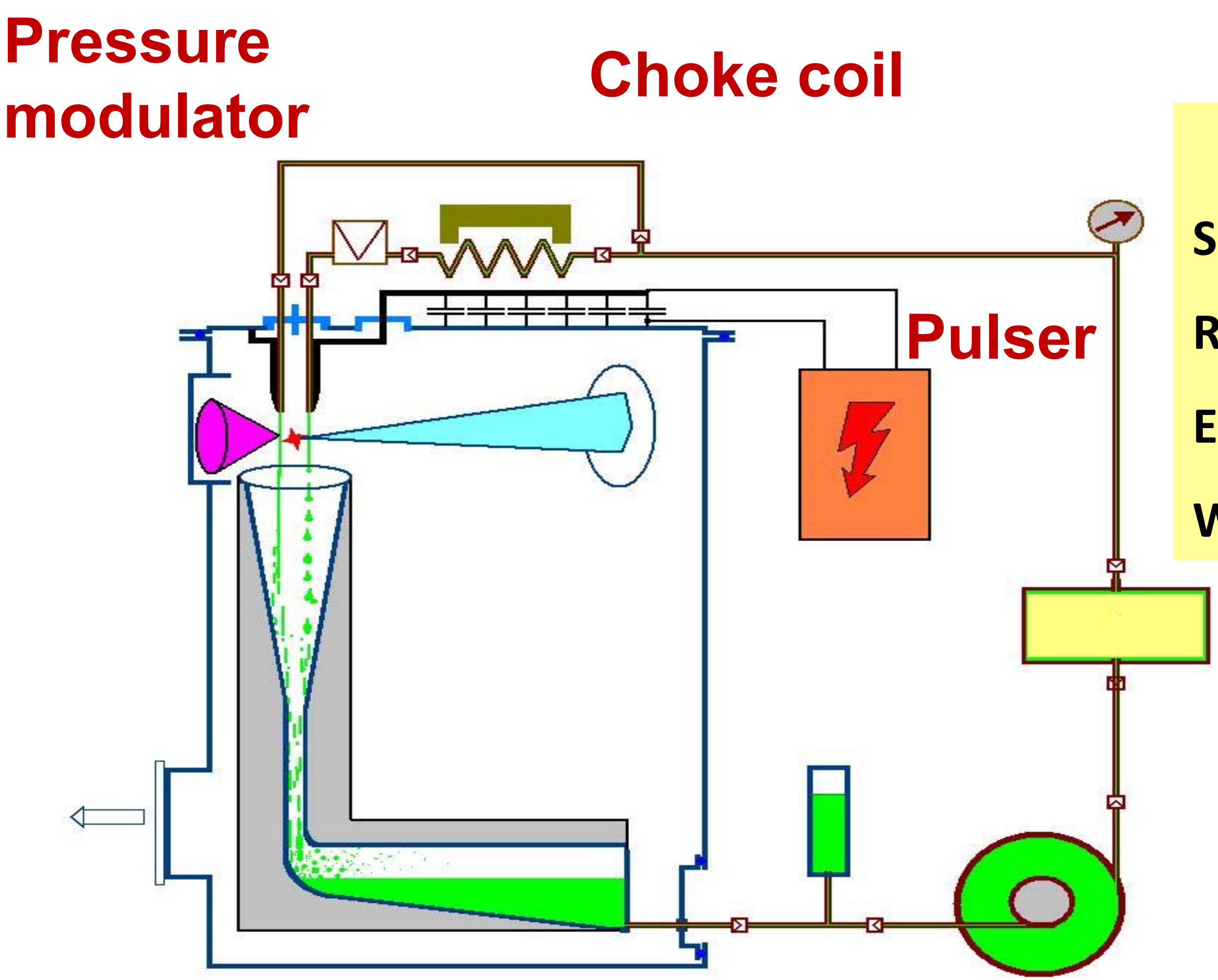
To use fast jets of liquid metal (tin or tin alloy) as the final part of discharge electrodes

Main design features of "New Type of DPP Source for EUVL "



- EUV collectable angle of $>\pi$ str.
- No moving part except liquid tin jets
- "New" electrode for every new shot, if V >~10-30 m/s
- Compact geometry leads to small inductance of the system and high CE
- Small size of full EUV source head (together with electrodes and cooling systems)
- Free orientation in space
- Estimated Liquid tin pump power does not exceed 200 W.

Principal scheme of JET set-up



Technical parameters:

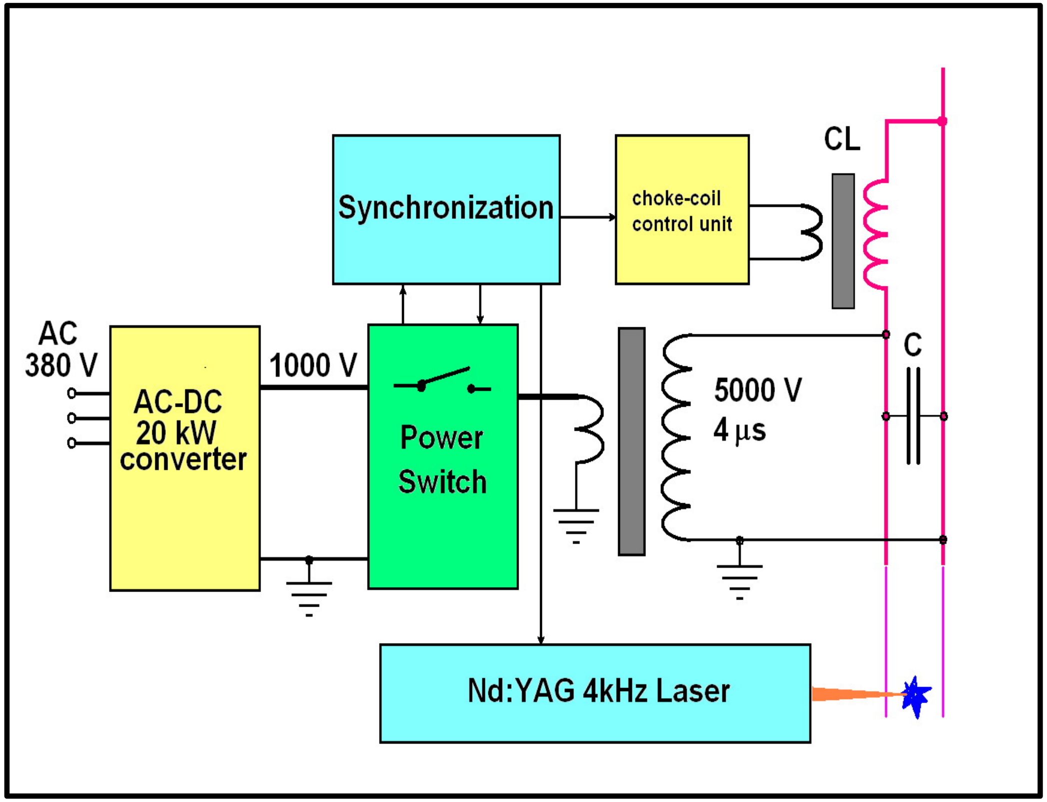
Speed of jets – 30 m/s

Rep. rate – up to 4 kHz

Energy in pulse – 2-5 J

Water cooling up to 12kW

Electrical circuit with pulser and laser synchronization



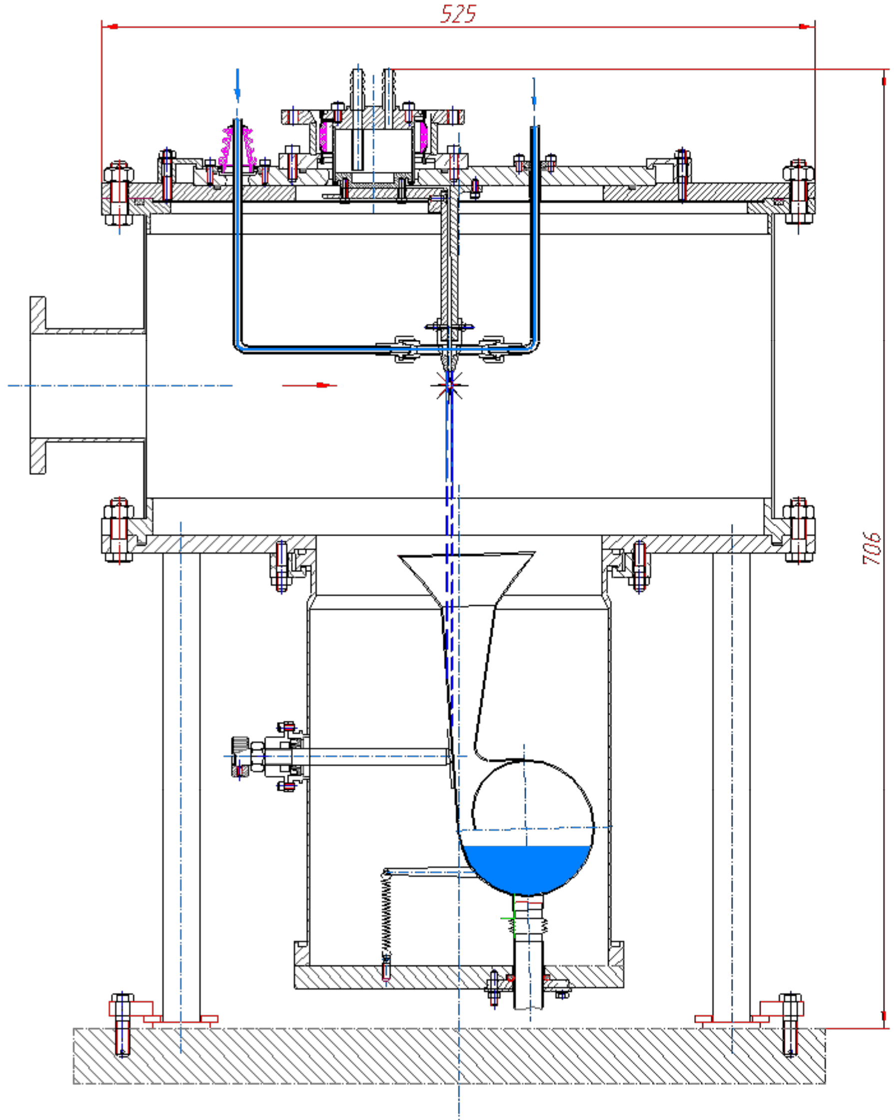
Pulser capabilities

Charge capability: 5 J (0.4μkF to 5kV) in 4μs pulse

Minimal burst time between pulses ~ 150μs

Long term output power 10kW, Short term (10min) 20 kW

Emergency system against shortcut


525
706

Demonstration of 2 jets

Technical parameters:

Speed of jets – 30 m/s

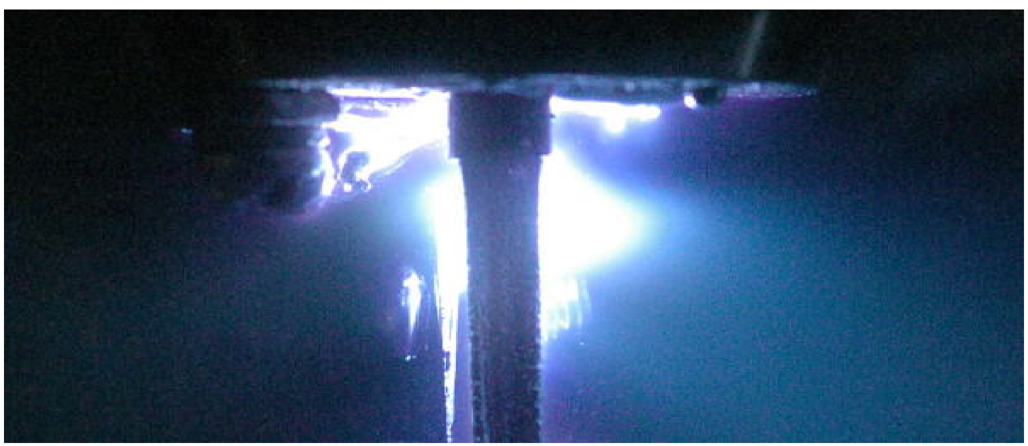
Rep. rate – up to 4 kHz

Energy in pulse – 2-5 J

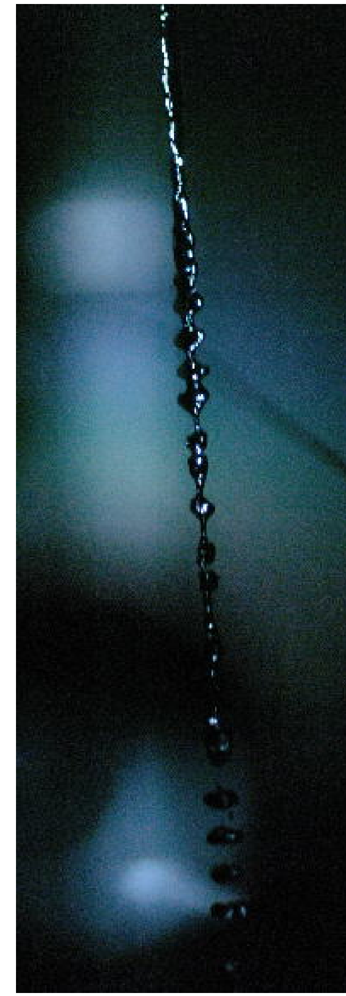
Water cooling up to 12kW

“cruising” power – 10 kW

Burst (few minutes) – 20 kW



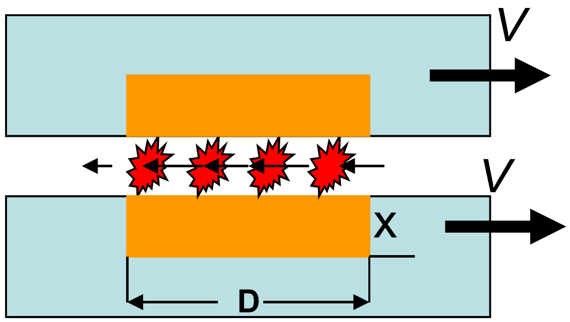
Jet fragmentation



Proof of principals.
Expected Advantages
Liquid metal electrodes heat load.

For the system with electrodes moving with velocity *V* an electrode in position "A" (and corresponding "A*") are being exposed to heat during time:

$$t_0 \approx D/V$$



D – size of area of interaction of hot plasma with tin surface. At D = 1 cm and *V = 3e2 cm/s* *t_0 = 3e-3 sec.* *At reprate r_p=5e4 Hz tau corresponds to approx 150 discharges and one can talk about "continuous" heating.*

At V=3e3 cm/s exposure time t_0= 3e-4 sec.

cut side

During time interval t_0 a thin layer x is being heated. The depth x can be estimated as x ≈ $(\chi t_0)^{1/2}$, where χ=0,43 cm^2/s. x ≈0.036 cm and x ≈0.01 cm correspondingly.

Assuming that the whole layer is being heated up temperature $T=T_0+\Delta T$ an energy balance equation:

$$\boxed{P_0 \approx \frac{2}{\eta} * v^{1/2} * D^{1/2} * L * C * \Delta T \sqrt{\chi}}$$

At V =3e2 cm/s, C=2,6 J/cm³K; ΔT ≈ 1000 K; D ≈ 1 cm, L=0,3 cm
Heat Limit is estimated as :

$$P_0 \approx 20/\eta \ kW$$

At V =3e3 cm/s, HL estimated as :

$$P_0 \approx 60/\eta \ kW$$

Proof of principals.

Expected Advantages

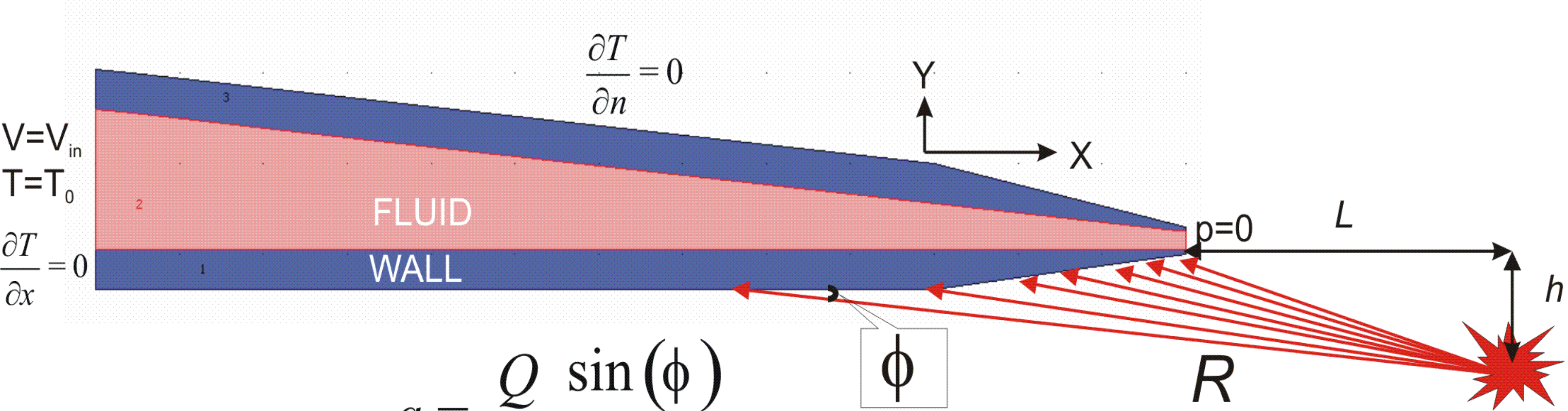
Metallic nozzle heat load.

Calculation of efficiency of cooling of metal nozzles by flux of liquid tin.

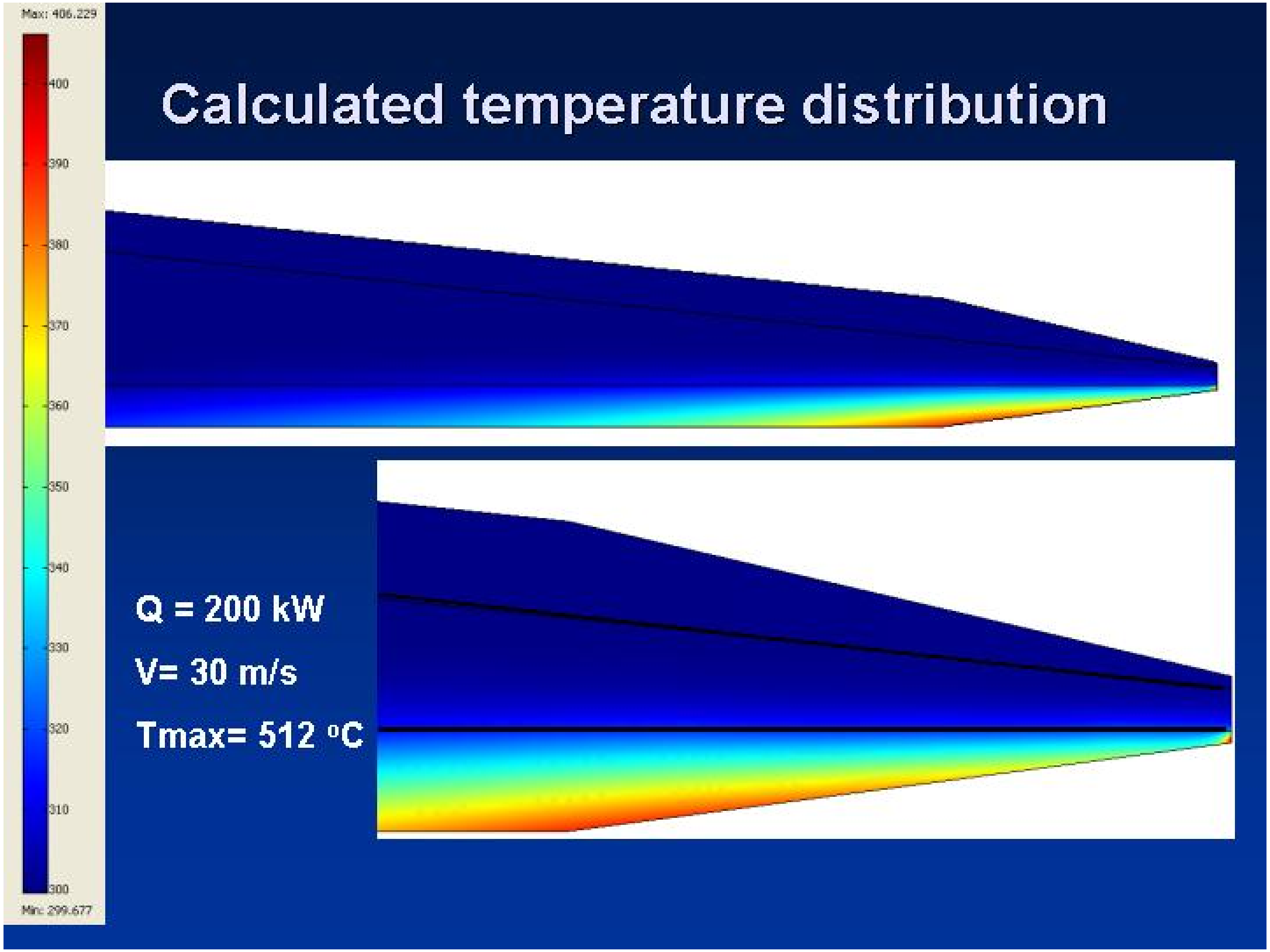
Fluid: Navier-Stokes and heat advection-conduction equations

Walls: Heat advection-conduction equation

$L = 1$ cm, $h = 2$ mm $T_0 = 300$ °C



$$q = \frac{Q}{4\pi} \frac{\sin(\phi)}{R^2}$$



Maximal temperature of external nozzle wall does not exceed 550 C, which is acceptable for main constructive materials

Proof of principals.

Expected Advantages

In-built debris mitigation features.

1. Decrease of droplets production in free standing thin metal slab.
2. Redirecting of part of droplets outside of EUV collectable angle due to high jet speed.
3. Concentration of atomic (plasma) debris in narrow solid angle outside of EUV collectable angle

Proof of principals.

Expected Advantages

In-built debris mitigation features.

1. Decrease of droplets production in free standing thin metal slab.

Hopes, predictions, not measured

Proof of principals.

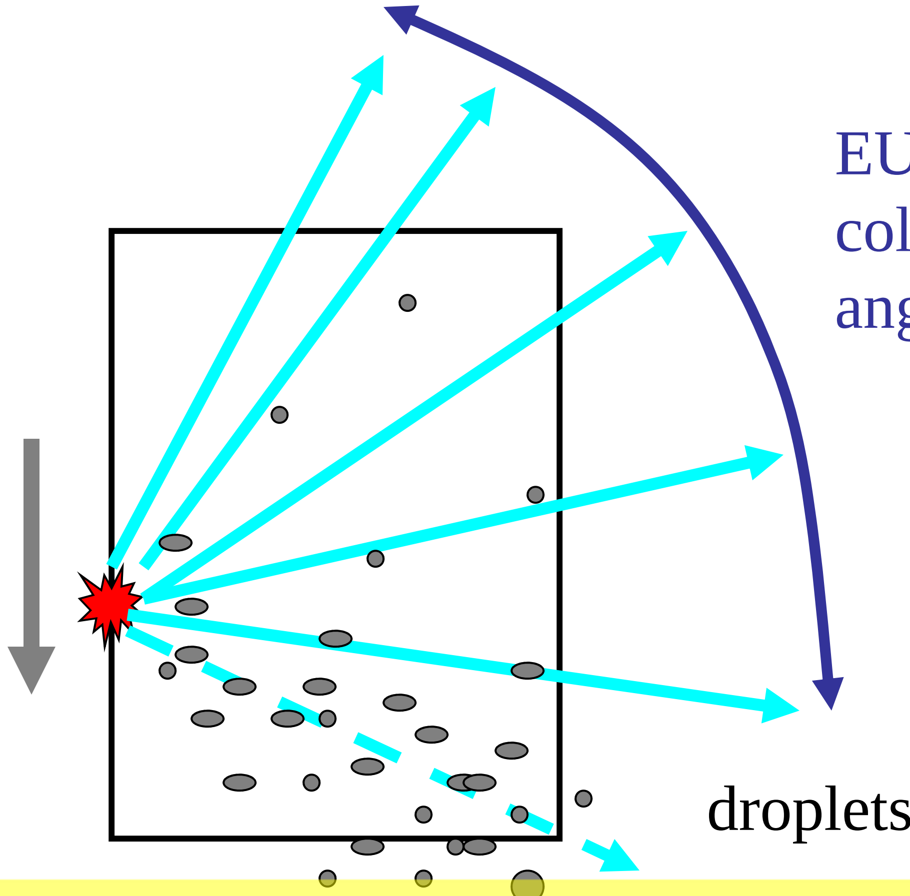
Expected Advantages

In-built debris mitigation features.

2. Redirecting of part of droplets outside of EUV collectable angle due to high jet speed.

Observed, can be calculated for given R at known V(R)

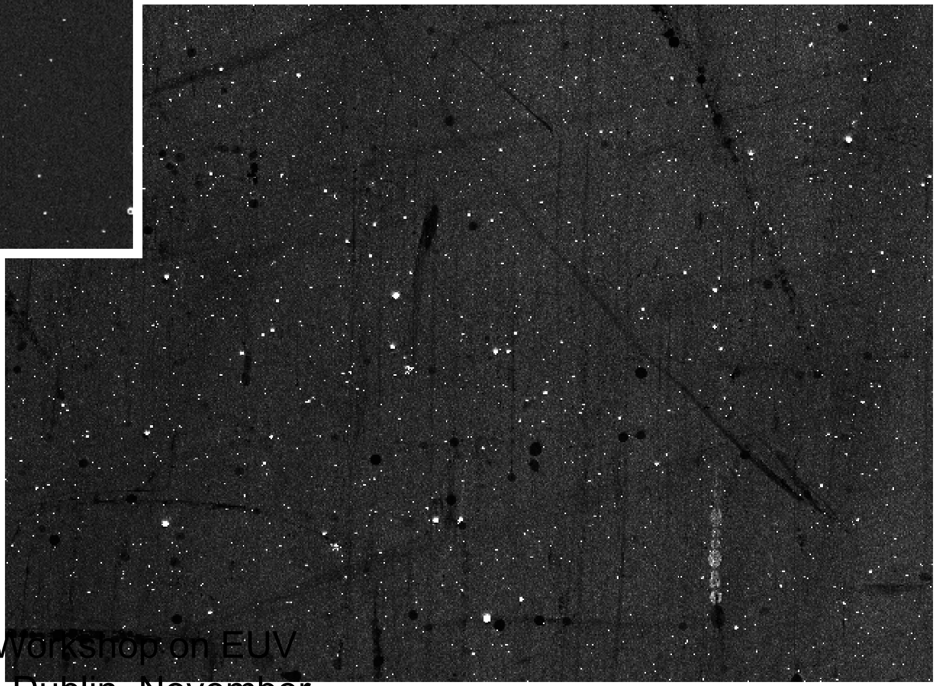
Expected Advantages and proof of principals.
Redirection of droplets



By increasing of the liquid electrode velocity it is possible to decrease number of droplets inside EUV collectable angle.

Expected Advantages and proof of principals.
Redirection of droplets.

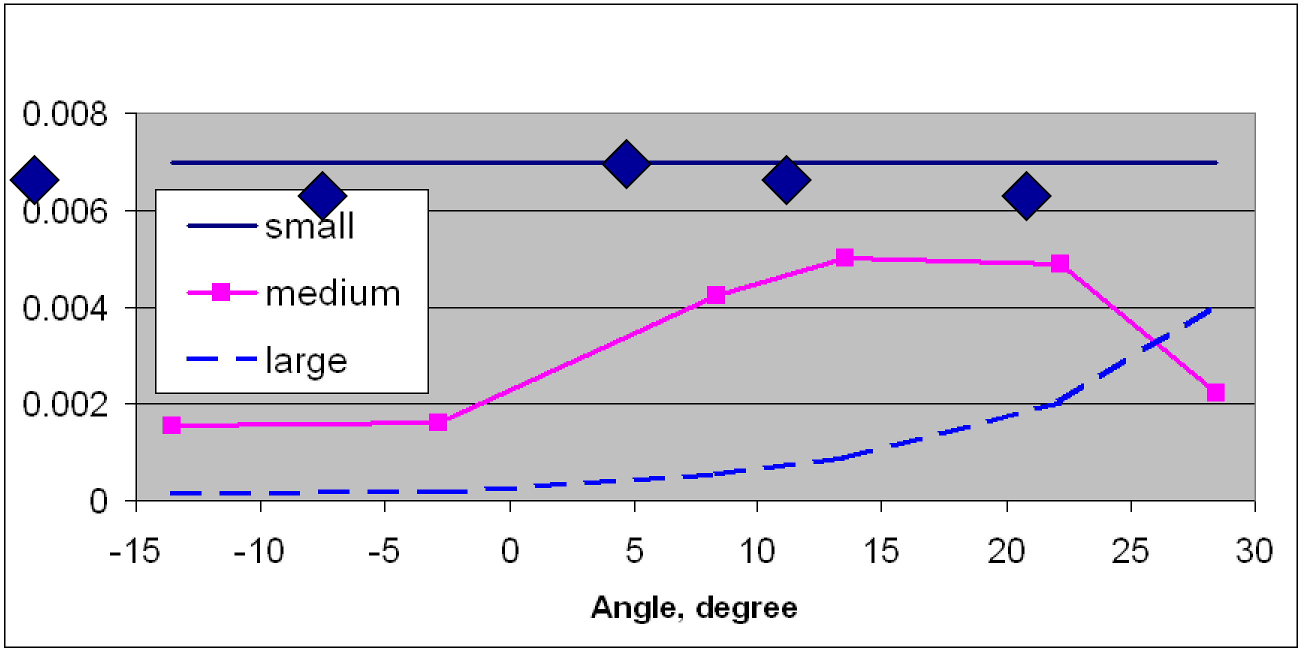
SEM images of witness samples for different direction of observation



Droplet coverage has maximum for direction outside EUV collectable angle

Expected Advantages and proof of principals.

Measured droplets coverage depending on angle of observation at different jet velocities



At a very small jet velocity – 3 m/s (blue curve) we did not see any significant dependence of a number of droplets from an angel in a vertical plane between jet direction and direction of observation. At an increased jet velocity (10m/s) preferred direction at approximately 20 degree from horizontal plane – pink curve – was observed.

Expected Advantages and proof of principals.

It is estimated that we may expect at least 100 times decrease of number of droplets in the direction above the horizontal plane.

+

Effect of droplet production mitigation due to free standing liquid metal jet (no reflections from solid metal surface)

Proof of principals.

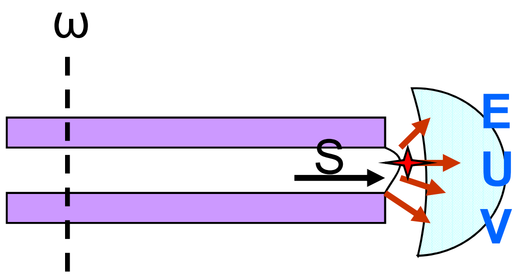
Expected Advantages

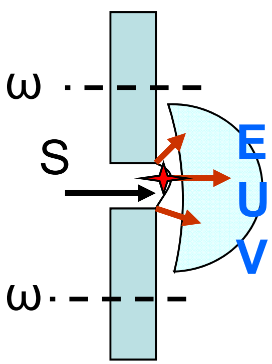
In-built debris mitigation features.

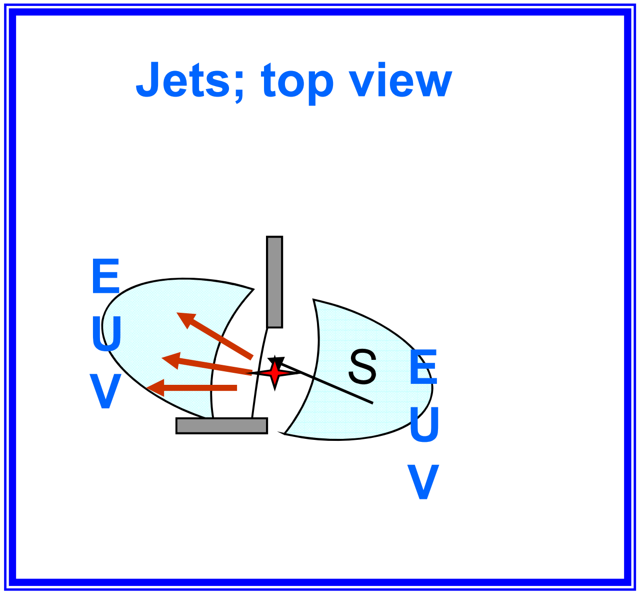
3. Concentration of atomic (plasma) debris in narrow solid angle outside of EUV collectable angle

Observed, not measured

3. Concentration of atomic (plasma) debris in narrow solid angle outside of EUV collectable angle



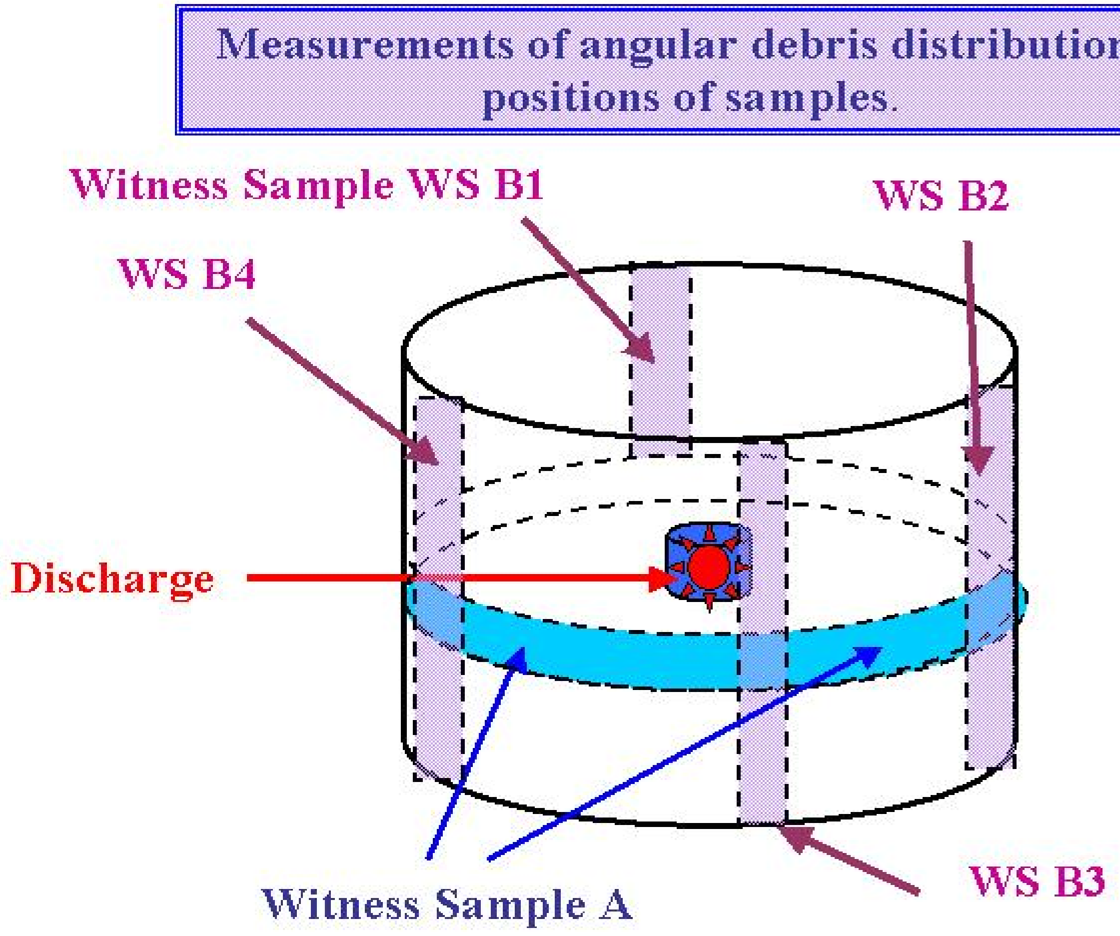




S – Poynting vector

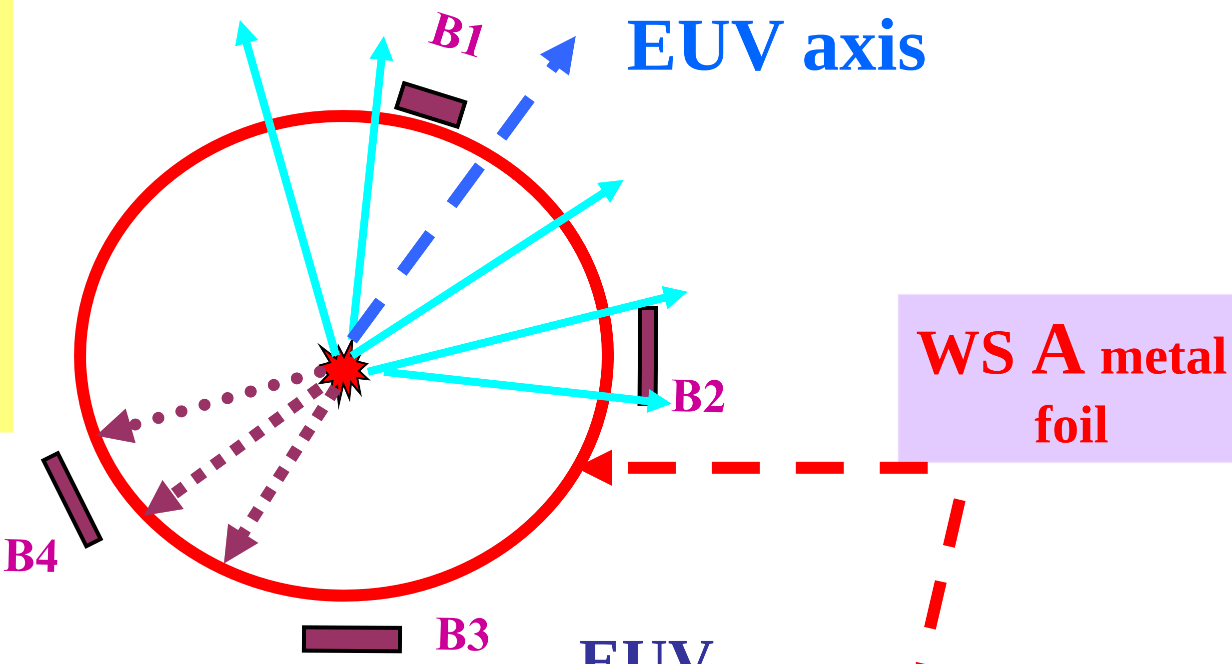
→-→ Pondemotoric forces

Expected Advantages and proof of principals.
In-built debris mitigation features.



Expected Advantages and proof of principals.
Redirection of atomic (plasma) debris.

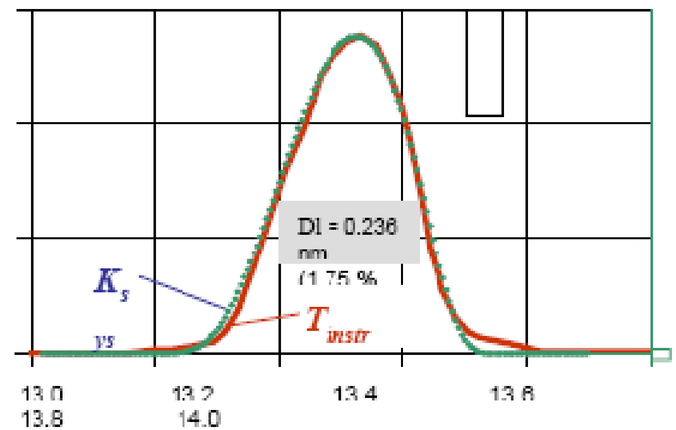
Electrode design allows to direct at least 90 % of expanding plasma opposite to EUV radiation



Expected Advantages and proof of principals.

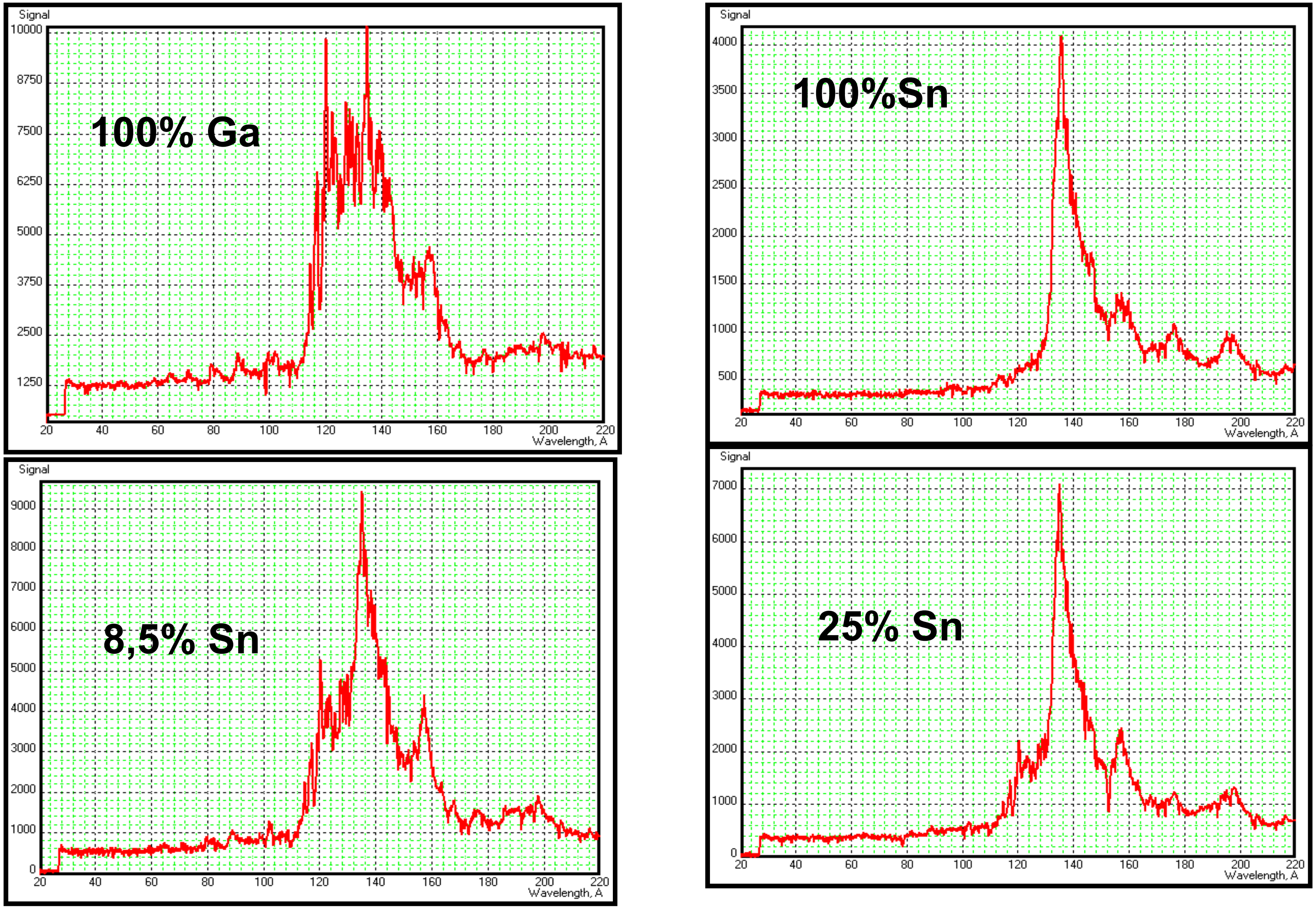
2% spectral band CE measurements

Phystex 2 MLMs Unit



Measurements Estimation	Conventional vacuum spark	Jet electrode system
Low melting temp tin alloy	1.5 %	1.4-1.5 %
tin	2.5 %	2.5 % (estimated)

Spectra of Sn:Ga alloys



	Sn 0.0% $T=29.7^{0}C$	Sn 8.5% $T=20.5^{0}C$	Sn 15% $T=50^{0}C$	Sn 25% $T=75^{0}C$	Sn 100% $T=232^{0}$ C
CE	**0.73%**	**1.3%**	**2.1%**	**2.9%**	**3.0%**
SP	**5.0%**	**8.4%**	**9.7%**	**10.8%**	**10.6 %**

Advantages:

• in-built debris mitigation features
• essentially higher heat load limit
• no overheated tin contacts with metal
• minimum of moving (rotating) parts
• “open geometry”
• free orientation in space…

Up to 20 kW dissipated power demonstrated for Ga:Sn alloy (in frames of MoreMoore Project)

60 kW for pure Sn jets– under construction (together with Prof.V.Borissov group as a part of RnD ISAN EUVL program)